

WHAT IS CLAIMED IS:

1. A hydrocarbon desulfurization process comprising the steps of:

(a) co-feeding a sulfur-containing middle distillate and a hydrogen-containing diluent to a reaction zone in respective amounts and under
5 reaction conditions sufficient to vaporize substantially all of said sulfur-containing middle distillate present in said reaction zone; and

(b) contacting the vaporized middle distillate with a sorbent comprising a promoter metal and zinc oxide in said reaction zone to thereby provide a desulfurized middle distillate comprising less than about 50 weight
10 percent of the amount of sulfur in said sulfur-containing middle distillate.

2. A process according to claim 1, wherein said hydrogen-containing diluent enters said reaction zone at a rate in a range of from about 1,000 to about 10,000 SCFB.

3. A process according to claim 2, wherein said sulfur-containing middle distillate boils in a range of from about 300 to about 750°F, has a mid-boiling point of more than about 350°F, and comprises more than about 50 ppmw sulfur.

4. A process according to claim 3, wherein said desulfurized middle distillate comprises less than about 50 ppmw sulfur.

5. A process according to claim 4, wherein said reaction conditions in said reaction zone includes a temperature in a range of from about 650 to about 850°F and a pressure in a range of from about 250 to about 600 psig, and wherein said sulfur-containing middle distillate enters said reaction zone at a rate in a range of from about 0.5 to about 10 LHSV.

6. A process according to claim 5, wherein said sorbent further comprises an aluminate and said promoter metal is selected from the group consisting of nickel, cobalt, iron, manganese, tungsten, silver, gold, copper, platinum, zinc, tin, ruthenium, molybdenum, antimony, vanadium, iridium, chromium, palladium, oxides thereof, precursors to oxides thereof, and combinations thereof.

7. A process according to claim 1, wherein said hydrogen-containing diluent comprises more than about 25 volume percent hydrogen and said hydrogen-containing diluent enters said reaction zone at a rate of from about 2,000 to about 8,000 SCFB.

8. A process according to claim 7, wherein said sulfur-containing middle distillate boils in a range of from 350 to 725°F, has a mid-boiling point of more than about 400°F, and comprises from about 100 to about 50,000 ppmw sulfur.

9. A process according to claim 8, wherein said desulfurized middle distillate comprises less than about 30 ppmw sulfur.

10. A process according to claim 9, wherein said reaction conditions in said reaction zone include a temperature in a range of from about 700 to about 800°F and a pressure in a range of from about 450 to about 550 psig, and said sulfur-containing middle distillate enters said reaction zone at a rate of from about 1.0 to about 5 LHSV.

11. A process according to claim 10, wherein said sorbent further comprises zinc aluminate and said promoter metal is a reduced-valence promoter metal having a valence which is at least one valence number lower than the valence of said promoter metal in its common oxidized state.

12. A process according to claim 11, wherein said promoter metal comprises a metal selected from the group consisting of nickel, nickel oxide, nickel oxide precursors, and combinations thereof.

13. A process according to claim 1, wherein said hydrogen-containing diluent comprises at least about 75 volume percent hydrogen, and said hydrogen-containing diluent enters said reaction zone at a rate in a range of from about 4,000 to about 6,000 SCFB.

14. A process according to claim 1, wherein at least about 75 weight percent of said sulfur-containing middle distillate present in said reaction zone is present in the vapor phase.

15. A process according to claim 1, wherein said reaction zone is a reaction zone of a fluidized bed reactor.

16. A hydrocarbon desulfurization process comprising the steps of:

(a) charging a sulfur-containing middle distillate to a reaction zone;

5 (b) simultaneously with step (a), charging a hydrogen-containing diluent to said reaction zone in an amount sufficient to vaporize substantially all of said sulfur-containing middle distillate present in said reaction zone; and

10 (c) contacting said sulfur-containing middle distillate with a sorbent comprising a promoter metal and zinc oxide in said reaction zone under reaction conditions sufficient to convert at least a portion of said zinc oxide to zinc sulfide using sulfur removed from said sulfur-containing middle distillate, thereby providing a desulfurized middle distillate and a sulfurized sorbent.

17. A process according to claim 16, wherein at least about 95 weight percent of said sulfur-containing middle distillate present in said reaction zone is present in the vapor phase.

18. A process according to claim 17, wherein said promoter metal is selected from the group consisting of nickel, cobalt, iron, manganese, tungsten, silver, gold, copper, platinum, zinc, tin, ruthenium, molybdenum, antimony, vanadium, iridium, chromium, palladium, oxides thereof, precursors
5 to oxides thereof, and combinations thereof.

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19. A process according to claim 18, wherein said sorbent further comprises an aluminate.

20. A process according to claim 19, wherein said sulfur-containing middle distillate boils in a range of from about 300 to about 700°F, has a mid-boiling point of more than about 350°F, and comprises more than about 50 ppmw sulfur.

21. A process according to claim 20, wherein said reaction conditions in said reaction zone includes a temperature in a range of from about 650 to about 850°F and a pressure in a range of from about 250 to about 600 psig, and said sulfur-containing middle distillate enters said reaction zone at a
5 rate in a range of from about 0.5 to about 10 LHSV.

22. A process according to claim 21, wherein said hydrogen-containing diluent enters said reaction zone at a rate in a range of from about 1,000 to about 10,000 SCFB.

23. A process according to claim 22, wherein said hydrogen-containing diluent comprises at least about 25 volume percent hydrogen, and said hydrogen-containing diluent enters said reaction zone at a rate in a range of from about 2,000 to about 8,000 SCFB.

24. A process according to claim 16, wherein at least 98 weight percent of said sulfur-containing middle distillate present in said reaction zone is present in the vapor phase.

10025050-121903

25. A process according to claim 24, wherein said sulfur-containing middle distillate comprises diesel fuel boiling in a range of from about 375 to 700°F, has a mid-boiling point of more than 500°F, has an API gravity in a range of from 30 to 38, has a minimum flash point of at least 100°F, and comprises from about 100 to about 50,000 ppmw sulfur.

26. A process according to claim 25, wherein said reaction conditions in said reaction zone include a temperature in a range of from about 700 to about 800°F and a pressure in a range of from about 450 to about 550 psig, and said sulfur-containing middle distillate enters said reaction zone at a rate in a range of from about 1.0 to about 5 LHSV.

27. A process according to claim 26, wherein said hydrogen-containing diluent comprises at least 95 volume percent hydrogen.

28. A process according to claim 27, wherein said hydrogen-containing diluent enters said reaction zone at a rate in a range of from about 4,000 to about 6,000 SCFB.

29. A hydrocarbon desulfurization process comprising the steps of:

(a) charging a sulfur-containing middle distillate comprising at least about 50 ppmw sulfur to a reaction zone at a rate in a range of from about 0.5 to about 10 LHSV, said reaction zone maintained at a temperature in a

10025050 121901

range of from about 650 to about 850°F and a pressure in a range of about 250 to about 600 psig;

(b) simultaneously with step (a), charging hydrogen to said reaction zone at a rate in a range of from about 2,000 to about 8,000 SCFB to thereby vaporize at least about 95 weight percent of said sulfur-containing middle distillate present in said reaction zone; and

(c) contacting said sulfur-containing middle distillate with a sorbent comprising reduced-valence nickel and zinc oxide in said reaction zone to thereby produce a desulfurized middle distillate comprising less than about 50 ppmw sulfur.

30. A process according to claim 29, wherein said sulfur-containing middle distillate consists essentially of diesel fuel boiling in a range of from 375 to 700°F, having a mid-boiling point of more than 500°F, having a API gravity in a range of from 30 to 38, having a minimum flash point of at least 100°F, and comprising from about 100 to about 50,000 ppmw sulfur.

31. A process according to claim 29, wherein said reaction conditions in said reaction zone includes a temperature in a range of from about 700 to about 800°F and a pressure in a range of from about 450 to about 550 psig, and said sulfur-containing middle distillate enters said reaction zone at a rate in a range of from about 1.0 to about 5 LHSV.

32. A process according to claim 29, wherein said sorbent further comprises zinc aluminate, and said sorbent comprises said reduced-valence nickel in an amount in a range of from about 0.5 to about 50 weight percent.

33. A process according to claim 32, wherein said reduced-valence nickel is present in said sorbent composition in an amount in a range of from about 4 to about 40 weight percent, and said reduced-valence nickel has a valence of less than 2.

34. A process according to claim 33, wherein said reduced-valence nickel has a valence of zero.

35. A hydrocarbon desulfurization process comprising the steps of:

(a) charging a sulfur-containing middle distillate to a reaction zone of a fluidized bed reactor;

5 (b) simultaneously with step (a), charging a hydrogen-containing diluent to said reaction zone in an amount sufficient to cause vaporization of at least about 75 weight percent of said sulfur-containing middle distillate present in said reaction zone;

(c) contacting said sulfur-containing middle distillate with a
10 sorbent comprising a promoter metal and zinc oxide in said reaction zone to

thereby provide a desulfurized middle distillate comprising less than 50 ppmw sulfur and a sulfurized sorbent comprising zinc sulfide;

(d) separating said desulfurized middle distillate and said sulfurized sorbent;

15 (e) contacting at least a portion of said sulfurized sorbent with an oxygen-containing stream in a regeneration zone under regeneration conditions sufficient to convert at least a portion of said zinc sulfide to zinc oxide, thereby providing a regenerated sorbent;

20 (f) contacting at least a portion of said regenerated sorbent with a reducing stream in an activation zone under activation conditions sufficient to reduce the valence of at least a portion of said promoter metal, thereby providing an activated sorbent; and

(g) returning at least a portion of said activated sorbent to said reaction zone.

36. A process according to claim 35, wherein said hydrogen-containing diluent enters said reaction zone at a rate in a range of from about 1,000 to about 10,000 SCFB.

37. A process according to claim 36, wherein said sulfur-containing middle distillate boils in a range of from about 300 to about 750°F and has a mid-boiling point of more than about 350°F.

10025050 121901

38. A process according to claim 37, wherein said reaction conditions in said reaction zone includes a temperature in a range of from about 650 to about 850°F and a pressure in a range of from about 250 to about 600 psig, and said sulfur-containing middle distillate enters said reaction zone at a
5 rate of from about 0.5 to about 10 LHSV.

39. A process according to claim 38, wherein said promoter metal is selected from the group consisting of nickel, cobalt, iron, manganese, tungsten, silver, gold, copper, platinum, zinc, tin, ruthenium, molybdenum, antimony, vanadium, iridium, chromium, palladium, oxides thereof, precursors
5 to oxides thereof, and combinations thereof.

40. A process according to claim 39, wherein said sorbent further comprises an aluminate.

41. A process according to claim 40, wherein said reaction zone, said regeneration zone, and said activation zone are located in separate vessels.

42. A process according to claim 35, wherein said hydrogen-containing diluent comprises at least 95 volume percent hydrogen, and said hydrogen-containing diluent enters said reaction zone at a rate in a range of from about 4,000 to about 6,000 SCFB.

43. A process according to claim 42, wherein said sulfur-containing middle distillate consists essentially of diesel fuel boiling in a range

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of from 375 to 700°F, having a mid-boiling point of more than 500°F, having
API gravity in a range of from 30 to 38, having a minimum flash point of at
5 least 100°F, and comprising from about 100 to about 50,000 ppmw sulfur.

44. A process according to claim 43, wherein at least 95
weight percent of said sulfur-containing middle distillate present in said
reaction zone is present in the vapor phase.

45. A process according to claim 44, wherein said sorbent
further comprises zinc aluminate.

46. A process according to claim 45, wherein at least 10
weight percent of said promoter metal is present in the form of a reduced-
valence promoter metal, and said reduced-valence promoter metal has a valence
which is at least one valence number lower than the valence of said promoter
5 metal in its common oxidized state.

47. A process according to claim 46, wherein said promoter
metal is selected from the group consisting of nickel, nickel oxide, nickel oxide
precursors, and combinations thereof.

48. A process according to claim 47, wherein said reduced-
valence promoter metal has a valence of zero.

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